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An Analysis of the System Installation Costs of Diurnal Ice Storage Cooling Systems for Army Facilities

by
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The three DIS systems had installed costs of $182/ton-hr, $206/ton-hr, and $513/ton-hr. The costs in the private sector for these same systems were estimated to be $130/ton-hr, $95/ton-hr, $93/ton-hr, respectively. Therefore, the USACERL systems cost from 40 to 452 percent more than systems installed in the private sector.

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FOREWORD

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This investigation was performed by the Advanced Energy Technologies Division of Science Applications International Corporation (SAIC) for the U.S. Army Construction Engineering Research Laboratory (USACERL), Energy Systems Division (ES), under Project CERL-ES-88-031 #C004. The USACERL project manager was Dr. Chang W. Sohn. The principal investigator at SAIC was Mr. Robin W. Taylor. S. Jennings, D. Ferraro, and R. Lorand, all employed by SAIC, contributed to this project. Dr. G.R. Williamson is Chief, USACERL-ES. The USACERL technical editor was Gloria J. Wienke, Information Management Office.

COL Everett R. Thomas is Commander and Director of USACERL, and Dr. L.R. Shaffer is Technical Director.

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1 INTRODUCTION

Background

The U.S. Army Construction Engineering Research Laboratory (USACERL) is conducting field demonstrations of three diurnal ice storage (DIS) cooling systems at Army facilities. The demonstrations are part of the Facilities Engineering Applications Program (FEAP). A static ice system (ice-in-tank) is in operation at Fort Stewart, GA,[1] an ice-on-coil system has been completed at the Yuma Proving Ground, AZ,[2] and an ice harvester was installed at Fort Bliss, TX.[3] These demonstrations are intended to introduce DIS cooling technology to Army engineers and to generate technical information for the development of an Army design guide on storage cooling systems.

During the installation of these three DIS cooling systems, USACERL incurred higher system construction costs than those reported in the private sector. An accurate assessment of system first cost is critical to predict the economic performance of storage cooling technology. The Army needs to identify the potential causes of these high costs for cost-effective use of storage cooling systems at Army facilities.

Objective

The objective of this research was to compare DIS system installation costs incurred by USACERL to those prevailing in the private sector and identify the potential factors responsible for the Army's higher costs.

Approach

The drawings and bid specifications for the three DIS systems were reviewed by a third party contractor, the Science Applications International Corporation (SAIC). Using standard cost estimating practice and experience in similar projects, SAIC estimated the installation costs. The estimates were then compared to the actual construction costs paid by USACERL. The installed costs for similar DIS systems in the private sector were obtained and compared to the costs of the three systems.

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[1] C.W. Sohn and J.J. Tomlinson, *Design and Construction of an Ice-in-Tank Diurnal Ice Storage Cooling System for the PX Building at Fort Stewart, GA*, Technical Report E-88/07/ADA197925 (U.S. Army Construction Engineering Research Laboratory [USACERL], July 1988); C.W. Sohn, G.L. Clerk, and R.J. Kedl, *Performance of an Ice-in-Tank Diurnal Ice Storage Cooling System at Fort Stewart, GA*, Technical Report E-90/10/ADA224739 (USACERL, June 1990).

[2] C.W. Sohn, G.L. Cler, and R.J. Kedl, *Ice-on-Coil Diurnal Ice Storage Cooling System for a Barracks/Office/Dining Hall Facility at Yuma Proving Ground, AZ*, Technical Report E-90/13/ADA228023 (USACERL, September 1990).

[3] C.W. Sohn, "Field Performance of an Ice Harvester Storage Cooling System," *ASHRAE Transactions, 1991*, Vol 97, Pt 2 (American Society of Heating, Refrigerating and Air-Conditioning Engineers, 1991).

System design and construction were evaluated by SAIC and compared to systems in the private sector. Improvements in the USACERL approach were recommended to reduce future installation costs. The findings on system first cost differences were summarized with respect to design, bid specifications, construction methodology, and other factors.

Scope

This report focuses on the three generic types of DIS cooling systems installed by USACERL under FEAP. Other types of commercially available ice systems were not evaluated, although a limited discussion of their comparable costs is presented.

Mode of Technology Transfer

It is recommended that the information in this report be included in a Technical Note (TN) on DIS cooling systems for Major Command (MACOM) and installation users, and in an Engineering Improvement Recommendation System (EIRS) Bulletin article for Division and District engineers. It is also recommended that this information be considered for inclusion in a PROSPECT course. This information was presented at a Storage Cooling System Workshop/Demonstration at Fort Bliss, TX, and New Mexico State University in May 1991.

2 PROCEDURE

Cost estimates for the three DIS system installations were prepared based on SAIC experience in DIS cooling systems, direct manufacturers' quotes, and *Means Mechanical Cost Data*.[4] The estimates were prepared based on the drawings and specifications released by USACERL for bids for actual construction. Individual costs for all items including labor and material were obtained or calculated. The costs were separated into civil (including structural and general), mechanical, and electrical. These costs were adjusted for the location of the installation in the United States. Overhead and profit of 12 percent and 10 percent, respectively, were added. Miscellaneous costs, such as permits, schedules, bond, cleanup, etc., were included. It was assumed that the mechanical contractor would also be the general contractor and subcontract the electrical and structural work as required. A 10 percent overhead was used for the subcontracted efforts. A 10 percent contingency was added to the entire cost estimate. These estimates were then compared to the actual costs.[5]

To compare these costs to DIS system costs in the private sector, several manufacturers, building owners, and utilities were contacted to obtain cost data. Both specific installation cost data and summary cost data were obtained. Based on SAIC experience, site visits, and discussions with site personnel and private sector contractors, several reasons for the high costs of the system installations were identified. Recommendations were also developed to reduce future system costs.

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[4] *Means Mechanical Cost Data, 1989* (R.S. Means Company, Inc., 1989).

[5] Cost adjustments were obtained by Personal Communication, R. Sides, Southland Industries, 1989, and C. Navarro, The Trane Company, 1989.

3 ANALYSIS OF ESTIMATED AND ACTUAL SYSTEM COSTS

System Descriptions

The three USACERL DIS cooling systems are all ice storage systems. A comparison of the specifications for each system is shown in Table 1.

Simplified schematics are shown for the DIS systems at Fort Stewart, Yuma, and Fort Bliss in Figures 1, 2 and 3, respectively. The static ice builder system (ice-in-tank) at Fort Stewart has 10 cylindrical ice storage tanks in which an ethylene glycol solution is circulated through polyethylene tubing in the tanks filled with water that freezes. The ethylene glycol solution transfers cooling through a plate-frame heat exchanger to the chilled water loop that cools the Main Exchange at Fort Stewart. An auxiliary chiller can supply the cooling if the DIS system is not functioning. The DIS system was designed to meet the building cooling load during a 6-hour peak period. During the remaining 18 hours, the 220-ton chiller charges the storage and cools the building.

The DIS cooling system at Yuma is an ice-on-coil system. An 80-ton air-cooled chiller provides ethylene glycol to the tank to build the ice. Water is circulated through the ice and transfers cooling to the chilled water loop in a shell-and-tube heat exchanger. The chilled water loop can supply the cooling for both the east and west wings of the barracks and the dining hall. The DIS cooling system meets the building cooling load during a 4-hour peak period. For the remaining 20 hours, a 220-ton chiller provides cooling to the building.

The DIS cooling system at Fort Bliss is a dynamic ice (ice harvester) system. It is composed of a 26-ton icemaker that makes ice on plates that fall into a 300 ton-hour storage tank during the defrost cycle. One pump is dedicated to icemaking and another supplies chilled water to the dental clinic's air handling unit. The DIS cooling system meets the building cooling load during a 4-hour peak period. For the remaining 20 hours, a 50-ton chiller meets the cooling load.

Table 1

System Specifications

	Fort Stewart	Yuma	Fort Bliss
System Type	Static Ice Builder	Ice-On-Coil	Ice Harvester
Storage Capacity (ton-hr)	900	1,000	300
Icemaker (ton)	200	80	40
Off-peak Chiller (ton)	178	220	50

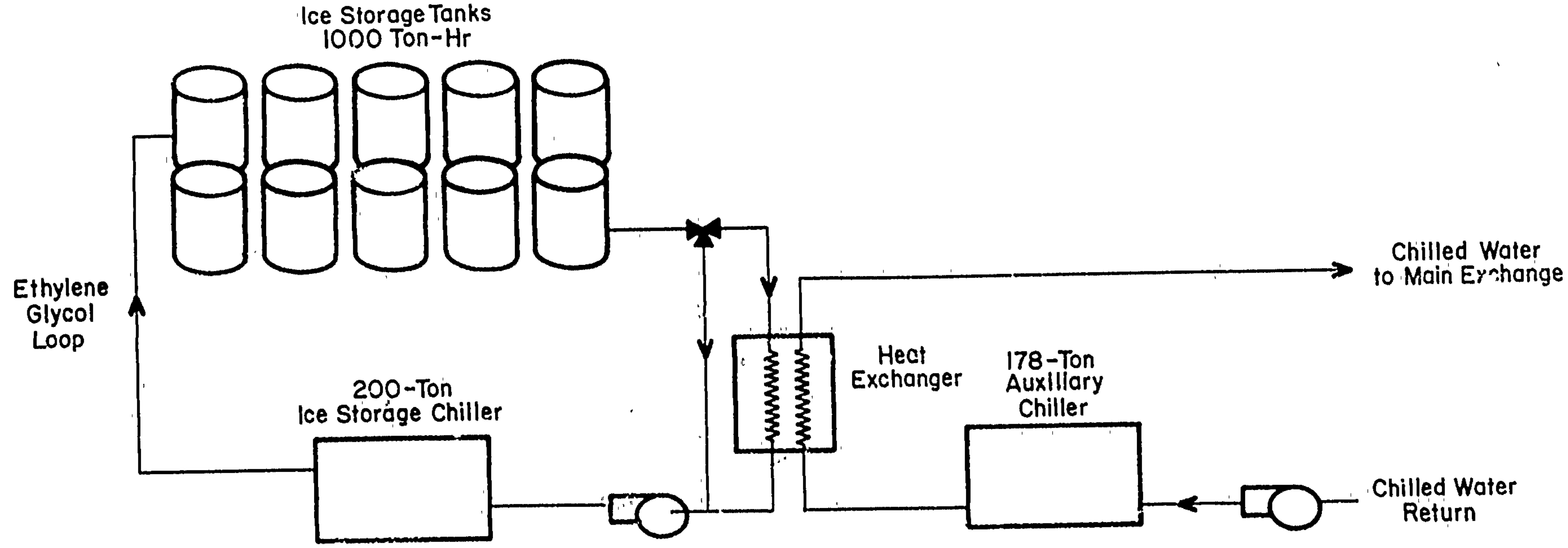

Figure 1. Static ice builder system at Fort Stewart, GA.

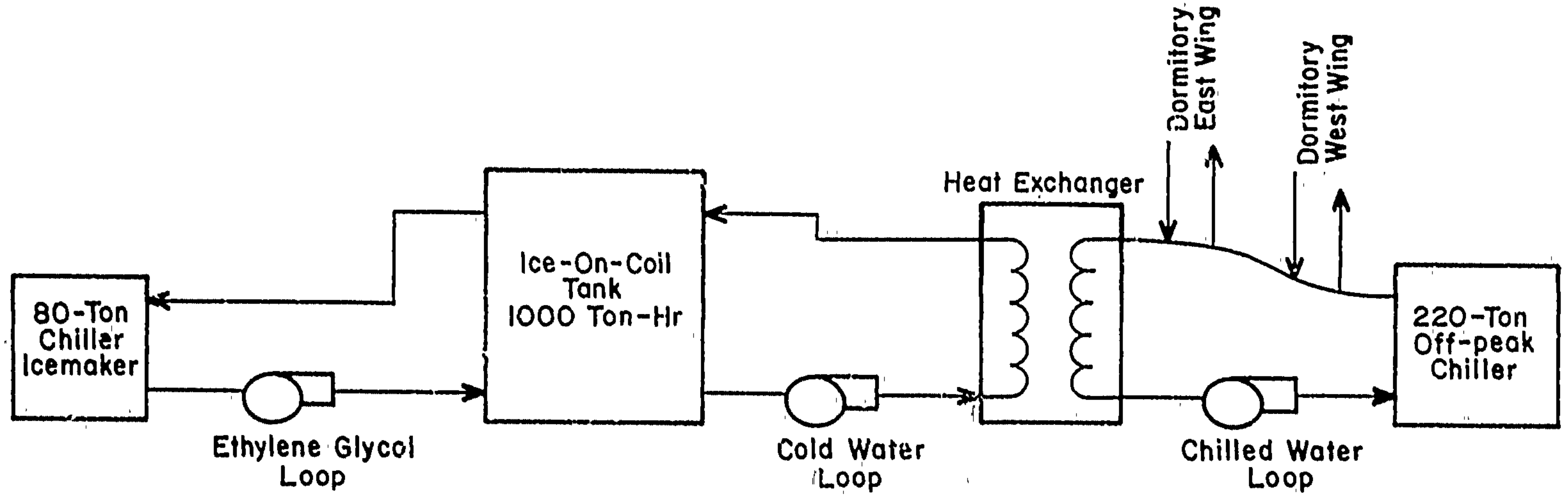

Figure 2. Ice-on-coil system at Yuma Proving Ground, AZ.

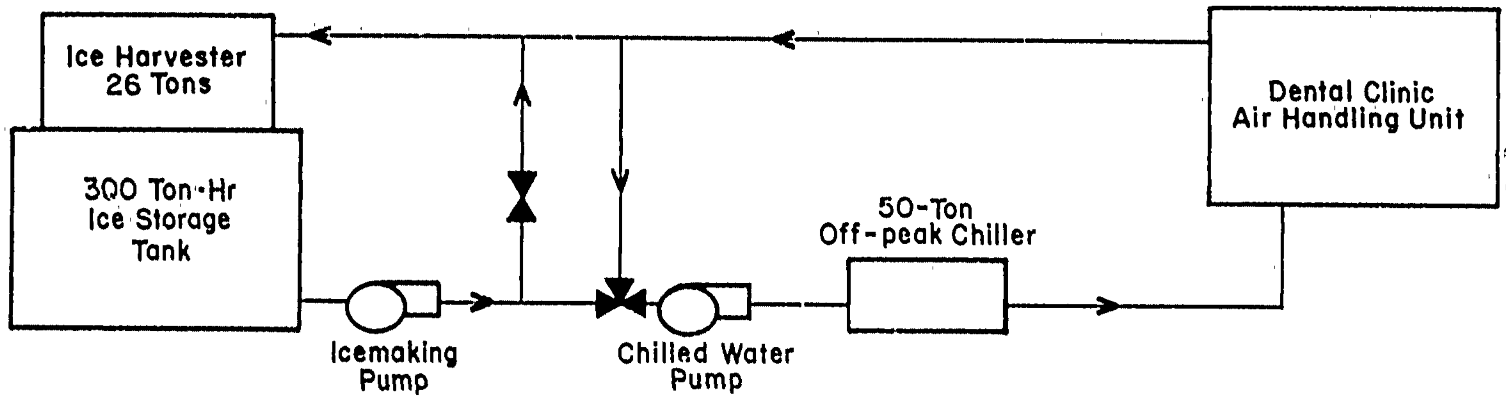

Figure 3. Ice harvester system at Fort Bliss, TX.

Installation Cost Estimates

The installation costs of the three Army DIS cooling systems were independently estimated by SAIC based on the bid specifications and design drawings that were used for actual construction. These estimates are summarized in Table 2. The breakdown between mechanical, electrical, and civil on a percentage basis is shown in Figure 4.

For Fort Stewart and Yuma, the cost breakdown by discipline is as would be expected for a typical retrofit DIS cooling system; the mechanical work is the major expense. The Fort Bliss installation costs were very unique for two reasons. The civil costs were very high primarily because a decorative brick wall and a wrought iron gate were built around the system equipment. The mechanical costs were a lower proportion of the overall installation costs because the packaged ice harvester system required less field work. The details of these installation costs are discussed below.

Actual Installation Costs Compared to Estimates

The actual costs for the three DIS system installations and the costs of the equipment supplied by USACERL are shown in Table 3. The SAIC estimated costs for Fort Stewart and Yuma were very close to the actual costs with a difference of 5 and 4 percent, respectively. For Fort Bliss, the SAIC estimate was 25 percent low. This was primarily an underestimation of the cost of the decorative brick wall. Also, the estimate did not consider that a general contractor would be used for this installation. The Fort Bliss engineering personnel had estimated the cost to be approximately $100,000, which is within 4 percent of the estimated cost. The methods used to estimate the costs produced very conservative estimates that are significantly higher than private system installations.

Table 2

SAIC System Cost Estimate

	Fort Stewart	Yuma	Fort Bliss
General and Civil	$8,667	$11,040	$42,423
Electrical	10,754	8,618	6,184
Mechanical	56,927	77,036	32,879
Subtotal	76,346	96,695	81,486
Permits, Bond, etc.	1,450	1,837	1,547
General Contractor Overhead and Profit	1,942	1,966	4,860
Subtotal	79,738	100,498	87,893
Contingencies - 10 percent	7,794	10,050	8,789
Total Costs	$87,712	$110,548	$96,682

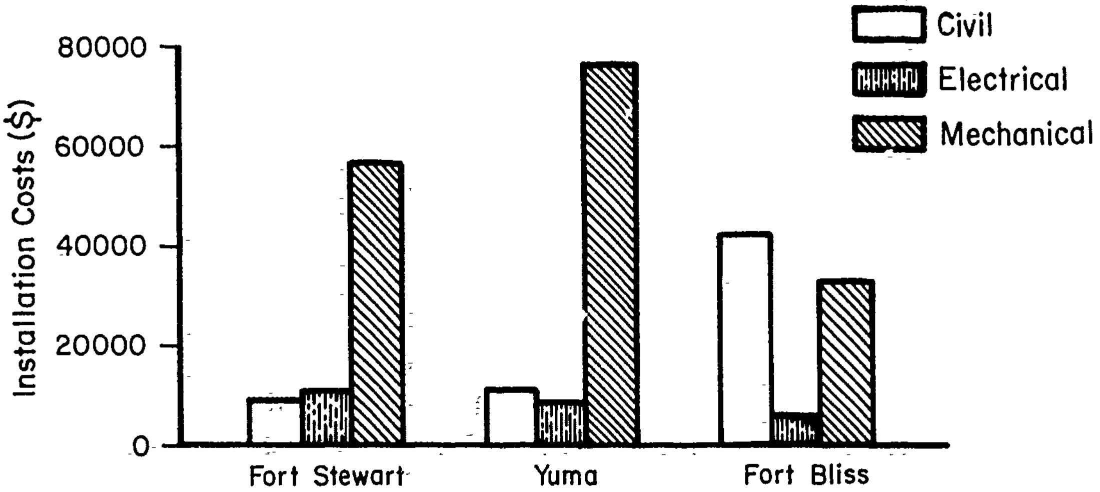

Figure 4. Installation cost breakdown by discipline.

Table 3

USACERL DIS System Actual Costs

	Fort Stewart	Yuma	Fort Bliss
Government furnished material costs			
Chiller/ice harvester	$52,793	n/a	$24,990
Heat exchanger	15,935	7,836	n/a
Storage tank(s)	53,460	60,198	n/a
Subtotal	122,188	68,034	24,990
Contractor installation costs	83,900	114,435	129,000
Percent Difference from SAIC Cost Estimate	5 percent	4 percent	25 percent
Total costs (rounded)	$206,000	$182,000	$154,000

A useful way to compare DIS system costs is to compare them by dollars per ton-hr. Table 4 shows a comparison of the three systems based on this factor.

It is apparent from Table 4 that the installation costs are a very significant portion of the total costs for Fort Stewart and Yuma and the predominant cost for Fort Bliss. As discussed below, normal costs for large DIS cooling system installations in the private sector range from $100 to 150/ton-hr.[6] Costs at the three USACERL installations are significantly higher. When the systems are compared on a dollar per ton of chiller charging capacity, the results are inconsistent from one site to the next. This is predominantly due to the sizing criteria used. The hours required to charge the system provide a guideline of how appropriately the systems were sized. The Fort Stewart chiller was sized to meet the nighttime cooling requirements and charge the ice tanks at the same time. Had the system been designed to use the existing chiller for nighttime cooling, the ice charging chiller could have been reduced in size to 70 to 90 tons. However, redundant chillers were mandatory for testing purposes to determine system performance and energy consumption of the DIS cooling system compared to the conventional cooling system.

Table 4

DIS Cooling System Cost Comparisons*

		Fort Stewart	Yuma	Fort Bliss
Chiller/ice harvester		$59	**	$83
Heat exchanger		18	8	n/a
Storage tank(s)		59	60	n/a
	Subtotal	136	68	83
Installation cost		93	114	430
	Total	$229	$182	$513
Ton-hrs of storage		900	1000	300
$/ton of chiller charging capacity		$1,030	$2,275	$5,923
Tons of capacity for cooling		200	80	40
Tons of capacity for icemaking		115	45	26
Required hours to charge		7.8	22.2***	11.5

* Costs are in dollars per ton-hr.
** Used existing chiller for icemaking.
*** Chiller was operating below design conditions.

[6] G P. Merten, et.al., *Operation and Performance of Commercial Cool Storage Systems, Volume 2, 1988, Cooling Season and Project Summary* (Electric Power Research Institute, September 1989).

Private Sector DIS System Costs

It is very difficult to obtain reliable actual installed costs for private sector DIS cooling systems. For retrofit installations, costs are quantifiable, but they often include costs that may not be directly attributable to the DIS cooling system. For new installations, it is difficult to differentiate between the DIS cooling system costs and the associated heating ventilation and air-conditioning (HVAC) costs. Specific site cost data was not as useful as composite data obtained from several sites because specific sites often have very unique requirements. Based on the procedures discussed earlier (see Chapter 2), Table 5 was developed to show the typical installed costs for private sector DIS cooling systems. The ranges in cost are relatively wide because installation costs of DIS cooling systems are very dependent on whether the system is new or a retrofit, requires new chillers or heat exchangers, requires decorative construction, and/or is easy to integrate into the existing structure and HVAC system.

Costs for a eutectic salt system are shown in Table 5 to compare with the DIS cooling systems. The eutectic salt system is not an ice storage system, but is a phase change system that stores energy in its heat of fusion and changes phase at 47 °F. The cost of this system is similar to a static ice builder in that it is composed of many modular containers of the salt, but has more economies of scale because a large, low-cost tank can be used.

A static ice builder system installed at Fort Stewart is modular but does not have significant economy of scale when installed in larger systems. This trend is typical for other types of ice storage. For comparison, a typical chilled water storage system has a large single tank that provides a significant economy of scale. The static ice builder can be very cost effective as a retrofit installation if the existing chillers can be operated at low temperatures to make ice. However, for large, new installations, the cost would be higher than for other system types because chillers may have to be purchased. The low end cost of $70/ton-hr can only be achieved if new chillers are not required and the ice storage tanks can be integrated easily into the HVAC system.

Table 5

Private Sector DIS Cooling System Installed Costs (in $/ton-hr)

	Static Ice Builder	Ice-on-Coil	Ice Harvester	Eutectic Salt
Small systems (<3000 ton-hr)	70 - 150	130 - 180	120 - 150	125 - 150
Large systems (>3000 ton-hr)	70* - 120	80* - 150	70 - 120	100 - 150

* These costs assume new chillers are not required.

The ice-on-coil system has an elaborate, manufactured, aboveground steel tank and internal heat exchange piping and header system. It is attractive for retrofits and small systems because it can be packaged at the manufacturer. It has some advantages in economy of scale over the static ice builder, but is still very equipment intensive in larger sizes. The ice-on-coil system will generally require new chillers in a retrofit application for larger DIS cooling systems.

The ice harvester DIS cooling system has some significant economies of scale primarily because it can use a low-cost tank. Small dynamic ice systems are generally more expensive than other types of systems. The advantage of large dynamic ice systems is that the tank becomes a significant factor in the total cost and, therefore, low cost tanks can keep the total system costs lower. To achieve the low cost of $70/ton-hr in large systems, a site-built, rather than a packaged system, should be used with a low-cost concrete tank. System installed costs without the tank can be as low as $900/ton or approximately $50 to $60/ton-hr. Tanks for ice storage systems usually cost $.75 to $1.25/gallon ($20 to $30/ton-hr). Large tanks (greater than 500,000 gallons) typical for chilled water storage systems can cost from $.35 to $.75/gallon.*

Table 6 shows installed costs for three examples of private sector DIS cooling systems. The static ice builder system was installed in the Washington, DC area on a corporate office building. The ice-on-coil system was installed on a dormitory in Texas. The ice harvester system was installed on a department store in the South. These systems are examples of very cost-effective DIS cooling systems and they fall in the low end of the costs shown in Table 5. For the static ice builder and ice-on-coil systems to meet these low costs, existing chillers would be used for storage charging rather than using new chillers as icemakers.

Table 6

Examples of Low-cost Private Sector Systems

	Static Ice Builder	Ice-On-Coil	Ice Harvester
Icemaking capacity	600 tons	80 tons	180 tons
Storage capacity	1900 ton-hr	680 ton-hr	3030 ton-hr
Required hours to charge	3.2 hr	8.5 hr	16.8 hr
Total installed costs	$279,000	$86,000	$218,000
$/ton-hr cost	$147	$126	$72
$/ton of chiller	$465	$1075	$1211
Installed cost without chillers	$130,000	$56,000	n/a
$/ton-hr cost without chillers	$68	$82	n/a

* Cost estimates were obtained by Personal Communication, Joe Drayer, Van Doren Industries, Inc, 1989; Gary Houbeau, Nielsen Construction Co., 1989; Doyle Barber, U.S. Lipp Industries, 1989; J.S. Andrepont, Chicago Bridge & Iron Co., 1989; Richard Peterson, DYK Industries, 1989.

Cost Comparison Between USACERL and Private Sector Systems

All of the USACERL DIS cooling system installed costs were unusually high compared to private sector system installations. Table 7 compares private sector and USACERL costs.

Researchers identified a number of reasons why the USACERL system costs were higher than the private sector costs. The reasons are listed below by the degree of impact, and are discussed in more detail in the following paragraphs. Site-specific causes of the high installed costs are also presented.

Major Causes:
- Systems were small
- Systems were retrofits vs. new installations
- Potential high markups on government woık
- Experienced contractors, but no experience with DIS cooling systems

Moderate Causes:
- Redundant chillers
- Instrumentation costs
- General contractor markup
- Prevailing wage requirements

Minor Causes:
- Lengthy specifications
- Lack of use of packaged systems

Table 7

System Cost Comparisons

	Static Ice Builder (Fort Stewart)	Ice-On-Coil (Yuma)	Ice Harvester (Fort Bliss)
USACERL costs	\$206/ton-hr	\$182/ton-hr	\$513/ton-hr
Comparable private sector costs (small systems)	\$110/ton-hr	\$155/ton-hr	\$135/ton-hr
Percent difference	87 percent	17 percent	280 percent
Comparable private sector costs (large systems)	\$95/ton-hr	\$130/ton-hr	\$93/ton-hr
Percent difference	117 percent	40 percent	452 percent

One of the major contributing factors to the high installed costs of the USACERL systems was that the systems were small. The storage capacity of USACERL systems ranged from 300 to 1000 ton-hours. In the private sector, an average size system is 4000 ton-hours and it is not uncommon to install systems as large as 15,000 ton-hours.[7] With most DIS cooling systems, there is a significant economy of scale. Small systems need the same components as large systems such as piping, pumps, valves, chillers, tanks, controls, etc. While there are some savings in material costs for small systems, there is little savings in labor costs and equipment rental.

All of the USACERL systems were retrofits on existing facilities. It is always true that a retrofit application is more expensive than an application to new construction. One possible exception is if existing chillers and heat exchangers can be used.

Contractors tend to charge higher overheads and fees on government work compared to private sector work. They also charge more on retrofits than new installations. For government projects, contractors often charge 10 percent overhead and 15 percent fee. For commercial retrofit systems, they usually charge 10 percent overhead and 10 percent fee and for new commercial installations, they usually charge 10 percent overhead and 5 percent fee. These rates are average and can vary significantly based on geography and local economic conditions. The major reason that contractors charge more on government work than commercial work is that they have more administrative costs and potential unforeseen problems hidden in the lengthy standard specifications.

Another major cause of the high costs of the USACERL installations was that although all the contractors were experienced, none of them had previously installed a DIS cooling system. Therefore, they probably included unusually high contingencies to cover their risk of installing an unfamiliar system. In two of the three installations, the base engineers believed that the contractor had overbid the project by at least $20,000.

The USACERL DIS systems had some degree of redundancy. This was necessary because the systems were test installations. Future systems would not need redundancy and extra instrumentation for research. All of the USACERL systems have installed instrumentation. Contractors are generally not familiar with instrumentation and probably overestimated their involvement in installing the sensors.

A general contractor normally is not required for small DIS cooling system installations. Because most of the work is mechanical, the mechanical contractor usually is the prime contractor, subcontracting the structural and electrical work as needed. One of the USACERL installations (Fort Bliss) used a general contractor who was the lowest among the four bidders responding to the request for proposal.

Government contracts require that all labor be at prevailing wages, which are comparable to union wages. In the private sector, this is not a requirement and for some aspects of the DIS cooling system installations, significant savings can be attained through using nonunion labor. This may not be an option for the Army.

For all of the USACERL sites, the specifications were very lengthy, and in some cases, the drawings did not show sufficient detail for contractors to provide a precise bid. When unknowns exist, contractors will include contingencies to reduce their risk. The government does not have the flexibility to simplify

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[7] G.P. Merten, et al.

the specifications (due to the required standard format), but more detailed drawings may be prepared to reduce the unknowns.

Fort Bliss was the only packaged system installed by USACERL. Using packaged systems can significantly reduce mechanical costs for small to medium sized systems. Note that, however, site-built systems may be more cost effective for larger systems.

Site-specific Comments

Fort Stewart Static Ice Builder System

In addition to the causes of high installation costs previously discussed, there were several site-specific reasons for the installation costs at Fort Stewart being high. The storage system consisted of 10 tanks (90 ton-hour nominal) with field-connected headers. A manufacturer now produces larger tanks (190 ton-hour nominal) that cost 30 percent less per ton-hour. A manufactured header system is also available to reduce the field costs. The overhead piping and supports used at this site were complicated and expensive. The site has complete redundancy since the auxiliary chiller and the ice storage chiller can each support the total cooling load of the building and the storage capacity. The site structural work added considerable cost to the project. Government-specified fences, curbs, and structural slabs were overdesigned compared to commercial installations.

Yuma Ice-On-Coil System

The Yuma DIS system cost came the closest to commercial installation costs. Some of the high costs were due to the ice-on-coil system being a field-assembled system rather than a packaged system. The piping and header assembly were expensive. This system would be more efficient and less expensive if freon was used directly in the storage system rather than using an ethylene glycol loop including an additional heat exchanger, pump, valves, etc. A relatively long piping run to the mechanical room and corresponding concrete removal also added to the installation costs.

Fort Bliss Ice Harvester System

The Fort Bliss system was very expensive on a dollar per ton-hr basis. The primary reasons were that the system was very small and a brick wall and wrought iron gate were built for aesthetic reasons. At this site, a general contractor was used. This was not entirely unnecessary because of the high cost of construction work performed by the general contractor. The tank, ladder, rail, and catwalk were provided by the DIS cooling system manufacturer at a cost of approximately $2.50 per gallon of tank volume. Some cost reductions could have been achieved if a generic tank could have been used. Below-grade concrete tanks would be less expensive for larger systems. Due to sloping terrain, the concrete slab became very deep at one end of the tank.

4 CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The installed costs for the three DIS system demonstrations ranged from $182/ton-hr to $515/ton-hr. DIS cooling systems installed in the private sector by experienced contractors would cost $70 to $180/ton-hr for comparably sized systems and $70 to $150/ton-hr for larger systems. The costs for three low-cost commercial DIS cooling systems similar to the USACERL systems ranged from $72 to $147/ton-hr. The demonstration systems cost from 40 to 452 percent more than systems installed in the private sector.

The high installation costs were due primarily to the following causes:

1. The systems were very small (300 to 1000 ton-hrs) compared to an average DIS system size of 4000 ton-hrs in the private sector,

2. The systems were retrofits on existing HVAC systems, not new installations,

3. The contractors were reputable and experienced, but previously had not installed a DIS system, and

4. Contractors who do work for governmental agencies tend to charge higher overhead and profit rates due to perceived higher administrative costs and risks.

The first three reasons for the high installed costs can be overcome in the future. The high contractor markups for government work may be harder to alleviate.[8] The costs of future systems will also be reduced by eliminating research instrumentation, using packaged DIS cooling systems, optimizing system size and design, and limiting decorative construction.

Recommendations

It is recommended that small DIS cooling systems (storage capacity less than 1000 ton-hr) be used only for new construction or for replacing exisiting chillers at the end of their useful life because retrofit application of small capacity DIS cooling system is expensive. The storage tank costs were less than ⅓ of the total system costs for the new construction or for replacement applications; the cost for the storage tank is extra (compared to the conventional system). The reduced differential construction cost would significantly reduce the payback period of the storage cooling systems. Retrofit application of small DIS cooling systems may be recommended only when the annual electric demand cost savings is greater than $100 for each kilowatt shifted from onpeak to offpeak.

If space is available, significant cost reductions can be achieved by using a chilled water storage system rather than an ice storage system. Although chilled water storage requires approximately four to seven times the storage volume of ice, it is usually compatible with the existing chillers. The unit storage cost of chilled water storage, however, is a strong function of the total storage capacity. Unless a free storage tank is available, chilled water storage is not recommended for a small system with a storage capacity less than 1000 ton-hr.

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